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NASA CR-101928

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ZERO GRAVITY LIQUID-GAS SEPARATOR-
ENGINEERING EVALUATION MODEL

FINAL REPORT

TRW
SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ZERO GRAVITY LIQUID-GAS SEPARATOR-
ENGINEERING EVALUATION MODEL

FINAL REPORT

Contract No. NAS 9-9525

(Period - 9 June 1969 to 19 September 1969)

13 September 1969

13288-6001-R0-00

Prepared For:

NASA Manned Spacecraft Center
Houston, Texas

TRW Systems
One Space Park
Redondo Beach, California

ABSTRACT

The operating principle of the TRW Zero-G Liquid-Gas Separator-Engineering Evaluation Model is described as well as the design of the actual device delivered under this contract. A brief description of the predelivery acceptance test and its results is also presented. The Separator itself, an Operation and Maintenance Manual, the Acceptance Test Procedure and engineering drawings necessary to reproduce the device are each submitted under separate cover.

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I. INTRODUCTION AND SUMMARY

The objective of this contract is to provide the government with an engineering evaluation model of a device capable of the separation of liquid and gas in a zero-gravity environment. To efficiently accomplish this separation with respect to reliability (number of moving parts), fraction of liquid removed from original two phase sample, and time required for the separation of liquid and gas, TRW proposes the surface tension screen device described in this report. Use of surface tension screens for the separation of liquid and gas has certain advantages over rival systems. Not the least of these advantages is the fact that there are no moving parts in a screen device (which increases system reliability). Also, such a device can be made entirely of stainless steel, rendering cleaning and sterilization extremely easy and reducing the compatibility concerns to a minimum. A zero-gravity surface tension screen system can be easily scaled up to larger capacities if required for a given mission. All that is required to operate a screen device such as described in this report is a source of gas pressure and a vacuum source, both of which are readily available in space missions of interest.

In the following sections of this report the construction and operation of the TRW Zero-G Liquid-Gas Separator is described and the predelivery acceptance tests are documented. The remaining deliverables of this contract; the Separator itself, the Acceptance Test Procedure, the Operation and Maintenance Manual, and the engineering drawings necessary to reproduce the device are each transmitted under separate cover.

II. PRINCIPLE OF OPERATION

The TRW Zero-G Liquid Gas Separator utilizes the principle of surface tension, acting across micronic screen pores, to obtain separation of the liquid phase from a sample originally containing liquid and gas. In this section the principle is briefly explained and its use in the present device is outlined schematically.

Referring to Figure 1, it is seen that, whenever

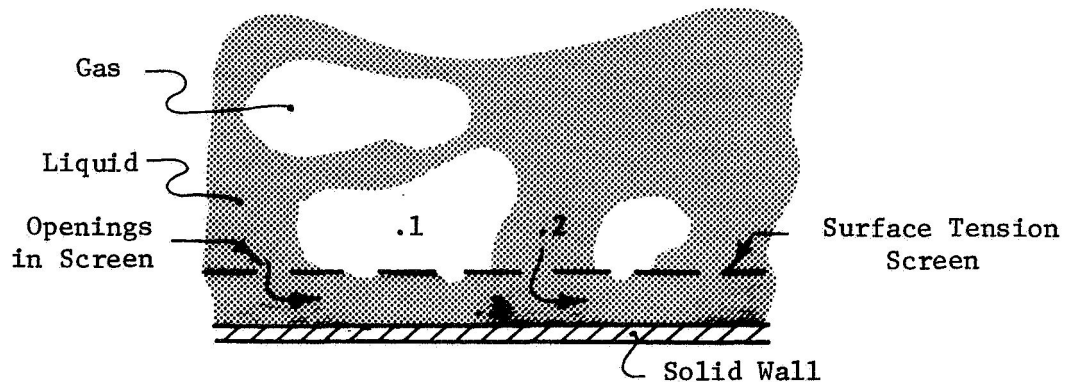


Figure 1. Principle of Surface Tension Separation of Liquid and Gas

there is liquid in contact with the screen on either side of it the resistance to flow, say, from point 2 to point 3 is much less than across locations on the screen where gas is in contact with one side of the screen, say, from point 1 to point 3. This is true since a certain excess of pressure at point 1 is required to overcome the force of surface tension acting across the micronic openings in the screen before gas bursts through the screen and enters the space between the screen and solid container wall. This critical gas breakthrough pressure differential, Δp_{σ} , is given by

$$\Delta p_{\sigma} = K \frac{\sigma}{r}$$

where σ is the surface tension of the liquid, r the equivalent radius of the surface screen openings, and K is a constant of proportionality near 2.0, depending on the type of screen being used.

The phenomenon is used to advantage in the TRW Zero-G Gas-Liquid Separator concept in which the separator's outer container has a close fitting concentric inner container of fine mesh screen (see Figure 2).*

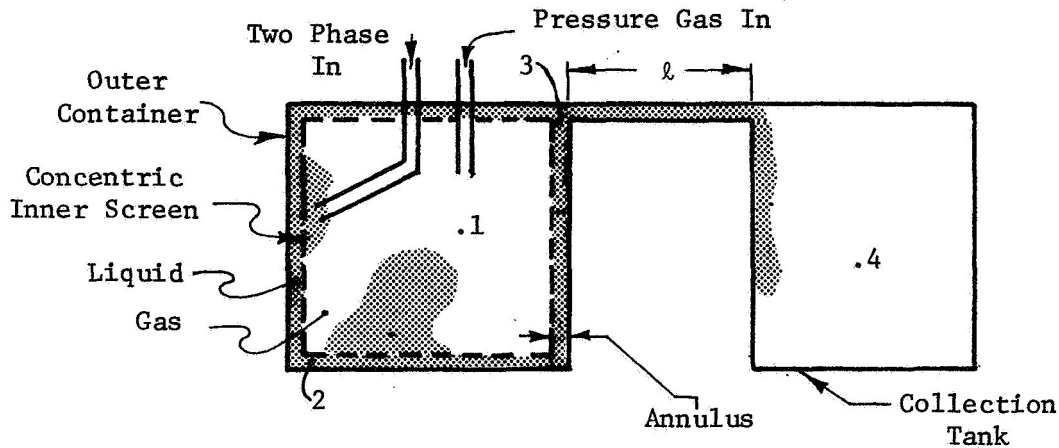


Figure 2. TRW Zero-G Liquid-Gas Separator Concept

In this concept the annular space between the screen insert and outer container serves as the pumping annulus from which gas is excluded by the action of surface tension acting across the micron openings of the screen. Consider the schematic of Figure 2. The point of maximum pressure difference across the screen is at point 3 where the transfer line, l , attaches to the Separator. During outflow of liquid through the screen and out of the Separator the minimum pressure in the annulus is at point 3, p_3 , and is given in a zero-gravity field, by

$$p_3 = p_1 - \Delta p_{fs} - \Delta p_{fc} \quad (1)$$

* For purposes of ease of handling and experimental monitoring of performance, the Engineering Evaluations Model of this concept was made with a surface tension screen insert in the shape of a right circular cylinder open on one end.

where p_1 is the pressure inside the screen volume, Δp_{fs} is the frictional pressure drop across the screen, and Δp_{fc} is the frictional pressure loss as the liquid flows in the annulus to the transfer line, ℓ .

Notice that the pressure drop across the transfer line, ℓ , does not enter Equation (1). During outflow, therefore, breakthrough of gas into the annulus can be avoided if

$$p_1 - p_3 = \Delta p_{fs} - \Delta p_{fc} < \Delta p_{\sigma}$$

a condition which is easily met with reasonably slow flows (Reference 1). However, when all the liquid from within the screen volume, space 1 of Figure 2, has been withdrawn all flow losses go to zero and p_3 equals p_4 , the pressure in the collection tank. Thus, to retain an annulus full of liquid, which will enable another two-phase sample to be processed, we must have

$$p_1 - p_4 < \Delta p_{\sigma} \tag{2}$$

by some factor of safety. This inequality is satisfied in the TRW Separator with a safety factor of 2. The device can therefore be cycled indefinitely to separate liquid from two-phase samples regardless of the total system pressure so long as inequality (2) is maintained.

III. TRW ENGINEERING EVALUATION MODEL

The TRW Zero-G Liquid Gas Separator - Engineering Evaluation Model was constructed to operate according to the principle described in Section II. In the interest of time, cost and usefulness to the government, the unit was made with the screen element shown schematically in Figure 2 as a right circular cylinder open on one end. Viton and 304 stainless steel were used throughout to minimize compatibility concerns. The element is shown in Figure 3, the outer container in Figure 4, and the top of the device, with attached valving, in Figure 5. A cross-sectional sketch of the assembled apparatus is shown in Figure 6. The capacity of the Separator is approximately 1900 ml, the screen is 375 x 2300 mesh and the mean screen to container wall gap is about 0.020". The complete drawings necessary for reproduction of the device are under separate cover. The unit was purposely over-designed to minimize warpage during the necessary welding operations. Subsequent devices could employ a screen element with corrugated screen walls which would eliminate the perforated support tube visible in Figure 3. Also, aluminum, properly anodized or coated with Teflon, could be used for the outer container and cap. The total weight could thereby be reduced below that of the present all stainless steel model. If tests are to be conducted with gases and liquids which are compatible with plexiglass, the top cap may be replaced with a plexiglass one and the operation of the separator observed from outside the unit.

The procedure for the operation of the unit is described in detail in Reference 2 but briefly, it consists of loading the unit initially so that the annular space between the screen and outer container wall is filled with liquid. Once this is achieved, operation of the unit with the proper pressure levels guarantees that no gas will enter the annular region and that liquid outflow from the unit will continue as long as there is liquid in contact with the interior surface of the screen element. When there is no longer liquid in contact with the interior surface of the screen element, the flow automatically ceases and, since no gas has entered the annular region between screen and tank wall, another two phase sample can be admitted to the space interior to the screen element and the liquid extracted from it as before.

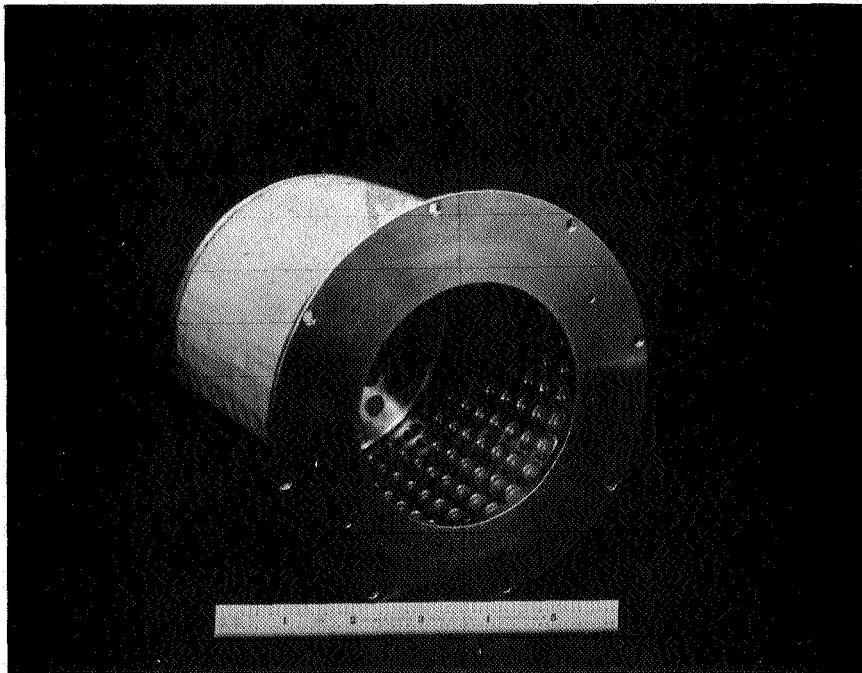


Figure 3. Separator Screen Element



Figure 4. Separator Outer Container

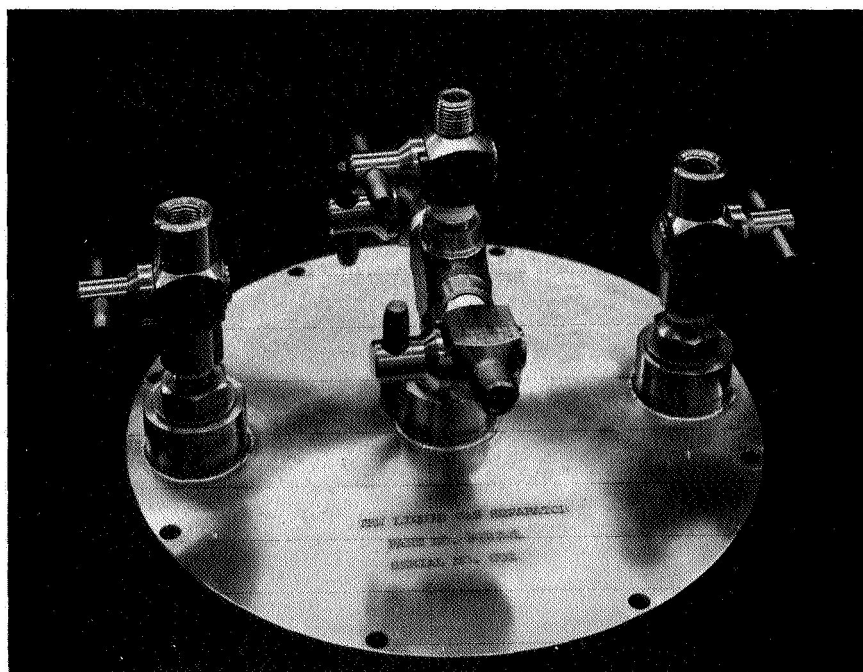


Figure 5. Separator Cap With Valving

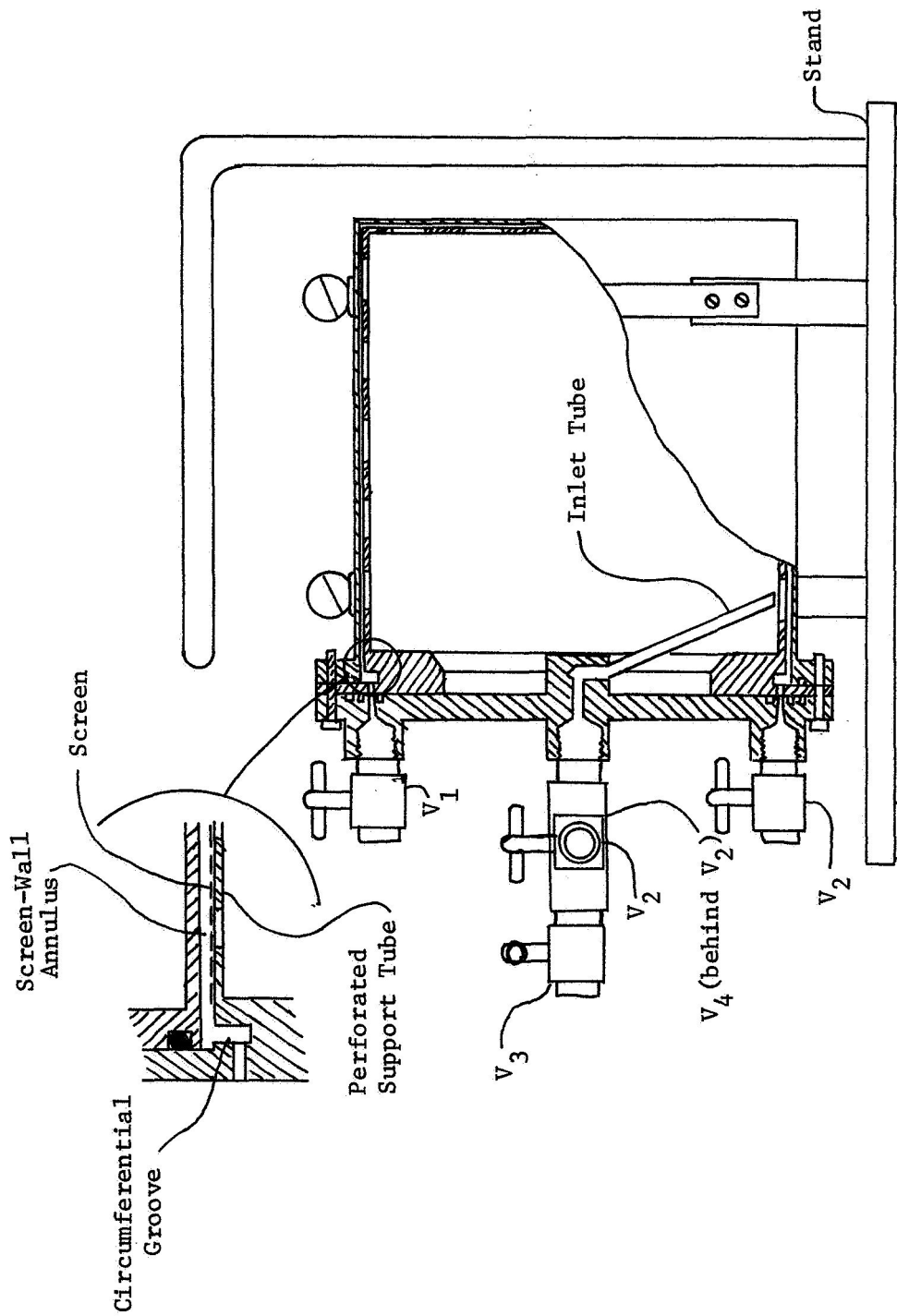


Figure 6. Cross Sectional Sketch of TRW Zero-G Liquid-Gas Separator and Stand

IV. PREDELIVERY DESIGN VERIFICATION AND ACCEPTANCE TESTS

Tests conducted at TRW prior to the delivery of the Separator to NASA Manned Spacecraft Center verified achievements of the design goals of the unit and justified the acceptance of the particular device as a properly functioning liquid-gas separator. This series of verification and acceptance tests consists of the following*

- o Leak Test
- o Residual Sample Test
- o Functional Operation Test
- o Opposing Pressure Head Test
- o Temperature Operation Test

The Leak Test is simply to verify that the unit is leak tight at 20 psig. In the Residual Sample Test the volume of liquid which remains in the annular space between the screen and container wall and in valves and passages is determined. The Functional Operation Test is to verify that the device can be cycled and still maintain a gas-free liquid outflow. A cycle is composed of lowering the pressure inside the unit, admitting the two phase sample, withdrawing the liquid from the sample (flow halts automatically when this is accomplished), and lowering the pressure in preparation for the next two phase sample. The Opposing Pressure Head and Temperature Tests are concerned with maintaining this cyclic operation under conditions of a one (1) psig back pressure and extremal temperatures of 40°F and 120°F, respectively. All of these tests were passed by the Engineering Evaluation Model constructed under this contract.

* For a complete description of the tests and the results obtained with the present Separator Model, see Reference 3.

V. REFERENCES

1. "Zero-G Liquid-Gas Separator - Engineering Evaluations Model," Vol. 1, TRW Technical Proposal No. 13288.000, submitted to NASA Manned Spacecraft Center 28 February 1969.
2. "Zero-G Liquid-Gas Separator-Engineering Evaluation Model," Operation and Maintenance Manual, TRW No. 13288-6002-R0-00.
3. "Zero-G Liquid-Gas Separator - Engineering Evaluation Model," Acceptance Test Procedure, TRW No. 13288-6003-R0-00.